Appendix E
Slope Stability Technical Memorandum

Subject:	Slope Stability Assessment
Objective:	1. To evaluate the slope stability of the eastern slope of the 12th Street Landfill and determine a conservative final design slope for that side of the site. 2. To determine if the relocation of the paper residuals from the eastern side of the 12th Street Landfill and the sediments from the Kalamazoo River to the proposed relocation areas would pose a slope stability issue. 3. To determine the preliminary design slopes for the remainder of the landfill such that the relocation areas do not extend into areas that may need to be cut as part of the final remedial design for the 12th Street Landfill.
Approach:	■ Identify site specific conditions that impact the stability of 12th Street landfill slopes. ■ Assign a range of assumed conditions to these critical site variables. ■ Select a targeted slope and model the results using the WinSTABL computer program for the range of conditions identified. ■ Assess the calculated safety factors against the implications of slope failure. ■ Select appropriate conservative design slope for the eastern slope along the Kalamazoo River. ■ Select preliminary design slope for other side slopes at the site to be used in future remedial design. ■ Assess the slope stability of existing landfill slopes with the addition of the two proposed staging pads to be constructed as part of the Emergency Response Action.
Outcome:	Critical site-specific conditions that impact slope stability were evaluated to provide inputs to the slope stability model. The Geotechnical Assessment presented in Appendix C identified heterogeneous fill and soil materials present along the eastern slope of the 12th Street Landfill. The fill materials varied but in some instance contained layers of paper residuals. These residuals fill materials had high moisture content and fine grain sizes with resultant low shear strengths. Groundwater conditions in this evaluation included a normal level measured during water table monitoring, and a conservative level condition where river flooding occurs and saturates the fills to the top of slope. In the conservative model case, the phreatic surface in the undrained fill is assumed to follow the profile of the slope, creating excess pore pressure conditions. Finally, the slope configuration assessment considered the additional loading from relocated residuals and 3 feet of required final cover soil. Based upon this information, two design slopes were identified and modeled (*i.e.*, 4H:1V and 5H:1V) with a range of conservative input assumptions. The 5H:1V slope was shown to provide the recommended 1.5 safety factor for the full range of modeled conditions on the eastern slope. For this slope configuration, safety factors for the various conditions were predicted using the WinSTABL computer program and ranged from 1.58 to 4.18. Consideration of failure implications including the unknown nature of the fill materials and the potential implications of slope failure adjacent to the re-located main channel

	of the Kalamazoo River were factored into the selection of the 5:1 final design slope. The preliminary design slope for the remaining sides of the landfill was assumed to be 4:1 recognizing the conservative input assumptions used in this analysis and different implications associated with a possible slope failure compared with the east slope. The material relocation staging areas are not in the areas that will need to be relocated or graded later. The existing landfill side slopes that are not along the Kalamazoo River were determined to be stable with addition of less than 4 feet of fill in the material staging areas on top of the existing landfill.

Background and Overview of Approach

The re-routing of the Kalamazoo River through the former powerhouse channel has an impact on the slope stability design for the eastern side of the 12th Street Landfill in several ways. First, placement of an erosion control system will require removal of trees and re-grading of the riverbank to support the rip-rap required by a permanent erosion protection system that protects the Landfill from a 500-year flood event. The resultant landfill slope needs to be stable both during and after construction and river re-routing. Secondly, the timing of the slope reshaping, originally scheduled to be performed with the Remedial Design/Remedial Action (RD/RA) scope, now needs to coincide with the Plainwell Impoundment Time Critical Removal Action (Plainwell TCRA) so that the erosion protection system can be installed. Therefore, as part of the Emergency Response Action being conducted by Weyerhaeuser at the 12th Street Landfill, a series of geotechnical data collection and design activities were performed to allow completion of the final design for the eastern slope of the 12th Street Landfill.

The overall approach to the design included the following activities:

- Identify site specific conditions that impact the stability of 12th Street landfill slopes.

  This assessment was focused upon assessment of the types of fill and soil materials near the eastern slope and understanding the implications of groundwater and surface water elevations on site.

- Assign a range of assumed conditions to these critical site variables.

  Key variables were assigned values to define conservative input conditions for use in the predictive model.

- Select a targeted slope and model the slope stability safety factor for the range of conditions identified.

  The WinSTABL computer program was used to perform the slope stability analysis. WinSTABL was developed at the University of Wisconsin - Madison (WinSTABL, 2002) as a Windows-based platform for the PCSTABL6 developed previously by Purdue University. WinSTABL was used to perform the iterative task of identifying the factor of safety for the worst-case failure scenario for each case using the simplified Bishop method. The simplified Bishop method was used to analyze circular or rotational failure surfaces. The circular failure surface generator performs a search for the critical failure surface based on failure initiation and termination regions established by the user. The WinSTABL program was run for three different scenarios that reflected different water table elevations and material strengths. These three scenarios were run on two slope geometries 5:1 and 4:1.

- Assess the calculated safety factors against the implications of slope failure.

  A typical conservative geotechnical safety factor for static slope stability at normal conditions is 1.5; however, no factor of safety is set by Michigan planning and guidance documents. A more conservative safety factor at normal conditions is appropriate for the 12th Street Landfill based upon: 1) the heterogeneity of fill types, volume and locations within the landfill, and 2) the significant negative implications of slope failure due to the site proximity to the Kalamazoo River.

- Select appropriate design slope for the eastern slope along the Kalamazoo River.
- Select preliminary design slope for the other side slopes of the landfill to be used in future remedial design and to identify where the relocation areas should be located.
- Assess the slope stability of existing landfill slopes with the addition of two proposed staging pads to be constructed as part of the Emergency Response Action.

Assumptions and Inputs to Model Runs

The WinSTABL model requires geometric and material strength characteristic input parameters in order to predict safety factors. Thus input parameters were established to represent a range of conditions that included the site specific groundwater conditions as well as various assumptions based upon the findings from the available geotechnical borings. The following assumptions were made to provide the needed information for the model and presented in Tables E-1 through E-3:

- **Groundwater** – Two groundwater table configurations were analyzed, one with groundwater generally matching the adjacent surface water elevation (Kalamazoo River) and wetland surface elevations (701 feet), and the second with groundwater levels at the landfill ground surface to simulate complete saturation of soil materials and rapid drawdown following a flood event. Groundwater elevations measured in monitoring wells at the site are presented in Attachment E-2.
- **Additional fill with residuals** – Additional fill will consist of re-graded existing cover materials, paper residuals, and possibly dredged river sediments. Two cases were modeled for this layer: 1) regraded residuals without additional river sediment at a natural moisture content unit weight, and 2) regraded residuals with additional river sediments at saturated unit weight. The additional fill with river sediment was also conservatively assigned the measured mobilized strength of the paper residuals (250 psf), and the unit weight of a 1:1 mix of native sand (including river sediment) and paper residuals (81.2 pcf).
- **Existing cover** – A thin stratum (2 to 7 feet thick) of sand overlies the paper residuals. This stratum was observed in the field and laboratory investigation to have the same physical properties as the native sand below the paper residuals. Identical geotechnical properties were assigned to both layers based on laboratory results. The existing cover layer was modeled as being 2 feet thick.
- **Fill with residuals** – This fill material will stay undisturbed in place throughout remediation. The paper residuals were observed to be heterogeneous in the field investigation, (performed by RMT in May 2007) changing rapidly both by depth and lateral extent. Paper residual thicknesses for the worst-case cross section of the final slopes were determined from the proposed final regrading and existing base grades found in the field geotechnical investigation.
- **Native sand** - Strength parameters for the sand unit are based on typical values from Das (1990) (Attachment E-4) and RMT experience. The native sand was modeled at an elevation of 700 feet. The native sand was observed in soil borings to begin at this elevation across the site.
- **Material Properties** – The material properties and groundwater conditions for the slope stability analysis derived from the above information are summarized in the tables below.

The three model cases described in the tables reflect the two different groundwater elevations and vary the assumed strength of the deposited paper residual materials.

Table E-1
Model Case 1 Material Properties for 5:1 and 4:1 slopes

MATERIAL	γ_{MOIST} (pcf)	γ_{SAT} (pcf)	SHEAR STRENGTH PARAMETERS (Total Stress Conditions) FRICTION ANGLE φ (degrees)	COHESION C (psf)	REFERENCE
Regraded residuals	47.4	88	10	526	RMT, 2007; BBL, 2001
Cover soil	110	131	32	0	Das, 1990; RMT , 2007
Fill with residuals	47.4	88	10	526	RMT, 2007; BBL, 2001
Sand subbase native soil	110	131	32	0	Das, 1990; RMT , 2007

Notes

Cases 1 assumes groundwater table elevation of 701 feet

Results for 5 1 and 4 1 model runs are presented in Attachment E-1

Table E-2
Model Case 2 Material Properties for 5:1 and 4:1 slopes

MATERIAL	γ_{MOIST} (pcf)	γ_{SAT} (pcf)	SHEAR STRENGTH PARAMETERS (Total Stress Conditions) FRICTION ANGLE φ (degrees)	COHESION C (psf)	REFERENCE
Regraded residuals	81.2	101.5	10	250	RMT, 2007; BBL, 2001
Cover soil	110	131	32	0	Das, 1990; RMT , 2007
Fill with residuals	47.4	88	10	526	RMT, 2007; BBL, 2001
Sand subbase native soil	110	131	32	0	Das, 1990; RMT , 2007

Notes

Case 2 assumes groundwater table elevation of 701 feet

Table E-3
Model Case 3 Material Properties for 5:1 and 4:1 slopes

MATERIAL	γ_{MOIST} (pcf)	γ_{SAT} (pcf)	SHEAR STRENGTH PARAMETERS (Total Stress Conditions)		REFERENCE
			FRICTION ANGLE φ (degrees)	COHESION C (psf)	
Regraded residuals	81.2	101.5	10	250	RMT, 2007; BBL, 2001
Cover soil	110	131	32	0	Das, 1990; RMT , 2007
Fill with residuals	47.4	88	10	526	RMT, 2007; BBL, 2001
Sand subbase native soil	110	131	32	0	Das, 1990; RMT , 2007

Notes·

Case 3 assumes groundwater table at landfill ground surface and complete saturation of landfill materials

Results for 5 1 and 4 1 model runs are presented in Attachment E-1

Results

The factors of safety predicted by the WinSTABL models are summarized below:

Table E-4
Stability for 5:1 Slopes

CIRCULAR FAILURE (BISHOP)		
FACTOR OF SAFETY	Model Run	CASE MODELED
4.18	Case 1	Existing water table, existing residual strength
2.86	Case 2	Existing water table, remolded residual strength
1.58	Case 3	Water table at landfill ground surface, remolded residual strength

Table E-5
Slope Stability for 4:1 Slopes

CIRCULAR FAILURE (BISHOP)		
FACTOR OF SAFETY	Model Run	CASE MODELED
3.52	Case 1	Existing water table, existing residual strength
2.35	Case 2	Existing water table, remolded residual strength
1.30	Case 3	Water table at landfill ground surface, remolded residual strength

Discussion of Results and Design Conclusions

- Regraded slope adjacent to Kalamazoo River.

  The proposed 5:1 slope is expected to be stable under all of the modeled conditions. Subsurface material conditions likely to be encountered on a short and long term basis have been determined to be stable. Michigan solid waste regulations stipulate analysis of slope stability but do not define a required factor of safety. Traditional geotechnical design practice applies a 1.5 factor of safety requirement, and thus, the calculated factors of safety are consistent with current practice for the modeled conditions.

- Preliminary remedial design landfill side slopes.

  The preliminary proposed 4:1 side slope to be implemented at a later time for regrading the existing landfill is expected to be sufficient for maintaining a stable final slope. This slope has been selected even though the 3rd Case of complete landfill material saturation does not meet the 1.5 factor of safety. The 1.5 factor of safety should be applied to normal conditions with a lower factor of safety acceptable for models of worst case conditions. The worst case conditions of complete saturation are not likely to occur because of the extent and thickness of the hydraulically conductive sand fill that is present in the landfill. The sand will act to convey water away from the landfill and is not likely to stay saturated when above local surface water elevations. The basis for this acceptance decision is the low probability of conditions that could result in potential failure taken together with the recognition that a slope failure away from the Kalamazoo River will not have the same environmental implications. Furthermore, the slope geometery modeled for the worst case cross section along the river was subject to modeling at a 4:1 slope. That slope was determined to be stable and will be reanalyzed with constrained geometry and material properties from a future investigation conducted before final remedial design of the entire landfill. Material properties and identified geometry are expected to increase the accuracy of the model and increase the factor of safety for slope stability. Based on this information, the location of the relocation areas were selected such that relocated material will not have to be moved at a later date.

- Existing slopes of the landfill and staging of material on the landfill.

  Material placed up to 4 feet in height in the two relocation areas on top of the existing landfill proposed in the design report are expected to be stable. A majority of the existing slopes on the landfill are 3:1 to 2:1 which is steeper than proposed grades. These existing slopes have been stable since the time of their placement. Newly placed material is planned to be less than 4 feet in height and set back from the existing slopes such that regrading in the future of slopes back to 4:1 would not require relocation of the new material. The 4:1 slope modeled for future side slopes was safe at material heights in excess of 15 feet, and therefore, the thinly placed staged materials are not expected to produce slope failures.

References

BBL. 2001. Geotechnical sample analytical data, 12th Street Landfill Operable Unit.

Das, B.M. 1990. Principles of foundation engineering. Second Edition. Boston Massachusetts: International Thomson Publishing.

Geraghty and Miller. 1994. Test Pit Investigation Technical Memorandum, 12th Street Landfill Operable Unit.

University of Wisconsin, Madison, Wisconsin. 2002. WinSTABL.

RMT, Inc. 2007. Geotechnical Investigation Technical Memorandum

Attachment E-1
Cross Section A-A'

Attachment E-2
Water Levels

Attachment E-3
BBL, Former Geotechnical Investigation

Attachment E-4
Textbook Reference